DISCUSSION ON

'TROPOSPHERIC PROPAGATION BEYOND THE HORIZON—II'

AT THE SYMPOSIUM, 28TH JANUARY, 1958

Mr. G. Millington: In the United Kingdom the experimental investigation of forward-scatter circuits went ahead on the ionospheric side, but as the papers show, a great deal of work is now in hand on the tropospheric side over a wide range of frequencies. This work is mainly scientific in nature, the aim being, as in the case of the ionospheric tests, to obtain a better understanding of the physical mechanism with a view to assessing the conditions for the successful practical application of such scatter circuits over long distances.

I should like to raise the question of where we stand with regard to the practical use of this mode of propagation. We know that links are in operation in America, as they are for ionospheric-scatter transmission, but we have already seen that in the latter case we must think very carefully before extending the application from one part of the world to another. Have any of the authors any views on this problem, in the light of the experience gained from their tests?

We hear of the use of high power, very large dishes and quadruple diversity, which may be feasible in military applications where expense is not a prime concern and it is vital to establish as long a circuit as possible over sea or over inaccessible territory; but is it desirable to use such a link where it is possible to establish a system of optical relays? This is partly an economic problem, but it is also one of technical performance.

We now know of some of the difficulties which the ionospheric circuits have encountered and of their possible interference with other services; and it is important to know how the tropospheric circuits will behave under conditions of extreme super-refraction, for example, and whether aircraft effects are going to be serious, at least in certain applications. The demonstration of music over the Start Point–Wembley link was quite impressive, but the ear is more tolerant than the eye, and it has yet to be demonstrated that these links can be used for high-quality television relays.

Much is being done by the use of error-correcting circuits and frequency-shift methods to overcome the troubles on the ionospheric circuits where the type of service is largely limited to those for which information can be stored for transmission at favourable moments. Apart from the cost of such devices, they would represent a very serious limitation in the case of tropospheric-scatter circuits, where so much has been made of the wide-band characteristics in planning the practical applications of this mode of propagation, including multi-channel telephony and television.

Dr. Pierre B. F. David (*France*): I understand that most of the work on forward-scatter propagation has been done either with continuous transmission or with telephony, and have heard very little mention of telegraphy. However, telegraph transmissions, such as teletype or digital transmissions, which we shall have to transmit sooner or later for every sort of data handling, are much more sensitive than telephony to the disturbance which may happen in the forward scatter, i.e. the rapid fadings. Of course, a better knowledge of the disturbance will be useful in plans for forward-scatter transmissions, but it also raises a more general problem. So far we have found this difficulty with fading or atmospherics on longer waves, but have succeeded in eliminating it by automatic gain control, diversity reception, etc., and now we are still convinced that the capability of a channel is limited by two parameters only, namely bandwidth and signal/noise ratio. Are we now confronted with a new transmission system in which a third parameter has to be taken into account, namely a very fine analysis of the disturbance?

Relative to this point I should like to ask Messrs. Angell *et al.* a few questions on their Fig. 16 and their high-speed pen recorder. My understanding is that no fading shorter than about $\frac{2}{3}$ sec is generally recorded, although, of course, the recorder alone could record some 10–20 times faster. This would mean a good deal in the use of telegraph senders and reducing speed for error correcting. Many of them would be ruled out if there were not more rapid fadings. In the same record, if we wished to analyse very small fadings, could we reasonably assume that the ordinate scale was approximately linear? Finally, the authors say that, in general, the smaller fading rates occurred during periods when the hourly variation in median level was below average. Were these periods of small variation related to periods of low average level?

Mr. F. A. Kitchen: It was pointed out in the papers by Mr. Joy, and in that by Messrs. Angell *et al.*, that under anticyclonic conditions the median value of the extra-diffraction field is below normal. This could be due to the partial diversion of energy by the subsidence inversion layers present from the effective scattering volume. It is interesting to consider a further possible diversion of energy due to weak superrefraction in the lowest atmospheric levels, with particular reference to Joy's 3-cm results. The semi-permanent low-level ocean duct is usually sufficiently high to have been excited by the transmitter in all these experiments. His receiving aerials were rather too high to detect a low-level partially-trapped signal component at any range. In these circumstances, the observed signal strength in the vicinity of the last few maxima of the interference pattern within the horizon would also be low. The attenuation rates in the purely diffraction region, indicated in Figs. 1 and 2 of the 3 cm paper, are generally less than normal, indicating the presence of weak superrefraction.

The partial diversion of energy from the effective scattering volume might further reduce the level of the scattered signal contribution in the extra-diffraction region. Day-to-day variations in the state of the atmosphere, with corresponding variations in the size and intensity of the duct, could lead to the intermittent existence of a coherent signal component in the received signal. The existence of such a coherent component, in addition to a Rayleigh-distributed component, has been mentioned by both Messrs. Joy and Rider. Its origin was not, however, specifically identified. The fact that similar effects were not reported in Mr. Joy's 10 cm paper is no doubt due to the reduced significance of the low-level ocean duct at the longer wavelength involved.

Dr. J. A. Saxton: During the past two years observations have been in progress at the Radio Research Station, Slough, on beyond-the-horizon transmission at 53 and 1 370 Mc/s. The source of the 53 Mc/s signal is the B.B.C. television station at

Kirk o'Shotts, and the length of the path is 530 km. It was thought before the work began that over this path the received signal might well be due predominantly to a more or less random scattering process. However, it is only seldom that the characteristics of the signal are those usually associated with such a signal; and for most of the time, although the signal is continuously fading, it has a greater degree of coherence than would be expected simply on the basis of a propagation mechanism involving more than a few transmission paths. Scattering of such a type appears, in fact, to give the dominant signal only when most or all of the path is under the influence of a strong meteorological depression. During marked anticyclonic conditions the signal is high with very slow fading, and it is then evident that only one or two transmission paths are concerned, which presumably involve reflections at well-defined inversion layers: an examination of the relevant meteorological data supports this conclusion. For much of the time the signal has characteristics suggesting a combination of these two extreme mechanisms, with the random scatter component playing a relatively minor part.

The measurements at 1 370 Mc/s are being made in collaboration with the Post Office, and the length of the transmission path is 150 km. There are many points of similarity between the signal recordings obtained at this frequency and those at 53 Mc/s, the main difference lying in the relative fractions of the time for which each type of signal occurs in the two instances. Thus, the rapid-fading signal occurs more frequently at 1 370 Mc/s than at 53 Mc/s.

It is considered that the results of these two investigations indicate the important contribution to beyond-the-horizon signals for much of the time due to refractive-index fluctuations confined to relatively restricted layers in the troposphere. Further support for this conclusion is provided by the results of vertical-incidence radar soundings of the troposphere, at a wavelength of 10 cm, which are also being made at the Radio Research Station.

Mr. G. A. Isted: The Doppler effects described by Mr. Rider and by Messrs. Angell *et al.* are probably correctly attributed by them to aircraft flying on or near the transmission path, but there are one or two points which need clarification.

Both papers describe tests and observations on aircraft flying in the vicinity of the receiving aerial, but make no mention of aircraft flying near the transmitting aerial. One would suppose that the effect must be reciprocal, but does the experimental evidence confirm this? I have observed the aircraft Doppler effect for long periods both at home while watching the television programme, and during the scatter tests carried out by Mr. Rider; on every occasion when the Doppler effect was observed an aeroplane was either audible or visible to me at the receiving site. On the other hand, attempts to correlate the aircraft flying near the scatter transmitter at Great Bromley with the received signal were completely unrewarding. We have concluded that it is extremely difficult to carry out a controlled test with individual aeroplanes in England, because of the large number of aircraft in the air at the same time, but a 2-way link would clarify the point I have raised because, by the law of reciprocity, the effect of aircraft should be observed simultaneously at both ends of the link.

A further point which cannot yet be explained was observed when Mr. Rider was carrying out his tests between Great Bromley and Grantham, during which his receiving site was situated near an airfield. Many observers came to the conclusion independently that aircraft going in to land caused pronounced Doppler effects. At these times the aeroplane would be about 200 ft from the ground and to the *rear* of the receiving dish at a distance of about 400 yds. One might conclude, of course, that the back/front protection of the dish was bad, but when the dish was turned away from the transmitter and directed towards the landing aircraft, no signal whatever could be detected. I am interested to find that Messrs. Angell *et al.* have observed similar effects.

Dr. G. L. Grisdale: Mr. Millington comments on the practical application of tropospheric scatter, which has been hardly mentioned so far, since this meeting is concerned mainly with propagation. When using the very adequate propagation information which has been presented for the design of communication systems, one is bound to make computations according to the simplified methods published, adjusting the system parameters to obtain the performance demanded of multi-channel links, or at least to approach it, under the worst propagation conditions from the long-term aspect, and taking into account the rapid fading.

In some of the information given about the law governing rapid fading there was a suggestion that a few valuable decibels might be saved. The rapid fading is not always Rayleigh distributed, as the simple calculations have assumed, but can be less deep than that given by the Rayleigh law. The hope that this saving would be useful was destroyed, because the fading does approach the Rayleigh distribution when the long-term average signal is weakest.

When attempting to attain the very high performance demanded by microwave link specifications for a 200-mile link with 24 telephony channels, the engineer finds that he needs quadruple diversity, 10 kW transmitters and 30, 60 or even 120 ft-diameter dishes. The receiver noise factor must be as good as the techniques permit. As Mr. Millington points out, this leads to expensive equipment; but I am not pessimistic about the practicability of the link, because the cost of large terminal installations would be offset by the saving on all the intermediate repeating stations of the line-of-sight links.

When listening to the recording of the frequency-modulated signal I felt that the speech had very adequate telephone quality. This was a single-telephone-channel link, and for 24 channels the modulation level would be reduced, but this demonstration used only a 0·5 kW transmitter with 8 ft aerials at each end to cover a distance of 173 miles.

I should like to ask Messrs. Angell *et al.* why only 20 kc/s deviation was used: was it to limit the threshold level in the receiver by using a narrow bandwidth, or was there an instrumental limitation at the transmitter?

The curves showing the variation of signal strength due to aircraft reflections display an amplitude variation which, I feel, is too regular for the explanation that the aircraft-reflected signal was beating with the tropospheric scatter signal. If the tropospheric scatter signal is fading very rapidly, surely its phase is also changing in this rapid way, while the aircraft reflection should have a steady, though changing, phase? Would this not produce a very irregular beat between the two waves?

Mr. H. Stanesby: Mr. Isted suggests a lack of reciprocity in tropospheric propagation to explain his observations on aircraft reflections. I cannot conceive why there should be such a lack of reciprocity, and until there is some theoretical basis for such a belief, I should prefer to look elsewhere for an explanation of his experience.

I do not see a great field for the application of tropospheric-scatter to civil communication inside Britain—or, for that matter, inside any country all parts of which are reasonably accessible. In this part of the world I should expect its most likely use to be in providing direct connections between the United Kingdom and countries on the other side of the North Sea. We must remember that tropospheric scatter must compete with conventional radio-relay systems, which can handle 600 telephone channels or television, using very-low-power transmitters and small aerials.

There are, I feel, a number of matters of immediate practical importance which urgently need attention. Nothing has been said about angle diversity, yet it would seem a simple matter to associate two feeds with a single aerial in such a way that two slightly diverging beams are obtained. If this were done at both ends of a tropospheric-scatter link, one might be able to use angle diversity instead of space diversity, and thus halve the number of aerials needed.

We should also like to know something more about the effect which time dispersion of the scatter components of the received signal has on intermodulation, when a multi-channel telephone system is provided using frequency or phase modulation. A question which is allied to this is the effect produced by aircraft flutter.

Mr. R. W. White: It is generally agreed that discontinuities or gradients in refractive index of the atmosphere play a major part in microwave propagation far beyond the horizon, but the relative importance of scattering and partial reflection appears to be disputed, and some protagonists on each side have invoked the aid of elegant but involved mathematics. I should like to suggest a simpler approach to the problem. In countries which enjoy long hours of sunshine and perpetually cloudless skies there is no doubt that elaborate and highly technical methods must be used to investigate the distribution of changes of temperature and moisture content in the atmosphere; but in this country we usually have an abundant supply of clouds, and I suggest that they are worthy of study. The shapes and arrangements of clouds can provide valuable qualitative information on typical distributions of moisture content in the atmosphere, and thus on a mechanism we are dealing with in long-distance microwave propagation. In particular I would stress the great variety of sizes and shapes of clouds, and the continually changing patterns which are involved.

A case of special interest is that of dull weather with more or less continuous cloud cover. Sometimes the base of such a cloud layer is surprisingly uniform in height, and if we fly above it the upper surface is relatively smooth and almost precisely horizontal: in such conditions I would expect propagation results to show approximations to reflection rather than random scattering, but because of residual roughness the reflection would be less effective at shorter wavelengths. I would expect scattering rather than reflection from large numbers of small fluffy clouds, or from the ragged fast-moving clouds associated with high winds. When the moisture content is too low or the temperature too high for the formation of clouds, there will still be complex and ever-changing distributions of moisture in the atmosphere, and I see no reason why the wide variety in size and shape of visible clouds should not provide a reasonable first approximation to what may be going on in a clear sky.

Dr. N. Knudtzon (*Norway*): It may be of interest to reveal that a military tropospheric-scatter system is now in operation in Norway; this system is implemented by S.A.D.T.C.,* and is the first part of a big military tropospheric-scatter system which is being planned by S.H.A.P.E. It consists of three links, respectively 360, 300 and 170 km long, and for test purposes the frequencies are chosen from the 1 and 2 Gc/s bands. The system has a capacity of 36 voice channels, some of which are used for telegraphy. Here I should like to point out that not in all places —and this also applies to commercial systems—are 600 channels necessary.

We have an extensive test programme for this system, covering propagation, interception and operation. With regard to the latter, we are analysing logs, and we hope to find from them answers to some of the questions on operation which Mr. Stanesby raises. It is too early yet to say much about the results of propagation measurements. However, I can indicate that the median transmission losses for the last two winter months appear to be at least 5 dB higher than estimated from the yearly median curves presented by the Lincoln Laboratory in 1955.

Brigadier E. J. H. Moppett: I cannot quite agree with Mr. Millington that tropospheric-scatter links are unsuitable for television relays, for whilst attending the I.R.E. Convention in New York I saw a demonstration of standard television transmitted over a 180-mile tropospheric scatter link. The subject chosen was a boxing match, and the picture quality was quite acceptable.

Mr. M. O. Felix (*Canada*): Dr. David asks whether teletype can be passed over a scatter link with reasonably few errors. We have had a 200 km link working on 5 Gc/s for some months; the long-term median carrier was only 15 dB above threshold, and dual diversity reception was used. Our test signal was a 75 words/min f.s.k. teletype applied at a level of − 16 dBm to one voice channel of the 48-channel circuit. So long as the signal was above the long-term median level, reception was excellent and the teletype machine errors were often more frequent than those due to propagation.

I agree that there is a need for more information on which to base the engineering of scatter equipment. For example, many measurements have been published of the depths of fading and the number of fades per second. What the design engineer needs to know is the rate of fading; at 5 Gc/s this often exceeds 300 dB per second.

Dr. R. L. Smith-Rose: I think we would all agree that we have to-day had a very useful Symposium of 24 papers presented by 30 authors. In general the papers fall into two categories, and these are in line with the objects of the Symposium, which were, first to obtain and bring forward the data on which engineers can plan, build and operate radio installations in the future; and secondly to investigate and try to understand the phenomena which are involved in the various modes of propagation, so that results obtained in one sphere of activity may be extended with an understanding of what will happen in some quite different circumstances.

There is a real difficulty in bringing together an adequate amount of propagational data of the desired type, obtained by research workers in one part of the world, and then deducing what is likely to happen elsewhere. As has been mentioned, we have a great deal of information available on what goes on in this part of the world and in America, in the temperate latitudes, and yet there is a great demand for the engineering of systems in other parts of the world where the conditions are quite different.

This type of investigation—as those who have been connected with the general study of the ionosphere for 25–30 years know—has been regarded as a sort of mathematical physicist's paradise. Apart from the people who steadily accumulate the data which the engineers require, the subject does provide almost unlimited opportunities for scientists to come along, postulate a theory and carry out a few measurements, completely ignoring all the measurements made by anybody else. In that way we arrive at the state I think we are in now in this particular field, in that we have a number of theories, each of which from the author's point of view appears to explain all the phenomena encountered. This may be a very satisfactory state of affairs for the time being, but sooner or later someone must co-ordinate all this work and bring it together.

Incidentally, one of the conferences I attended recently in New York was a joint radio and meteorological meeting; and although there were one or two radio papers, they were overshadowed by those on meteorology; but I am not sure that I have any clearer idea of what the troposphere looks like after having heard the meteorologists discuss it than I have to-day from hearing the radio engineers and scientists discuss it.

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* S.H.A.P.E. Air Defense Technical Center.